A LIMEN COLOR MIXER

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1. General Description

The limen color mixer described in this article was designed to permit fine variations in the percentages of the color components entering into a rotary mixture of colored papers or discs, and to allow accurate control of the duration of the exposure of the colors and the intervals between the exposures. The problem for which the mixer was originally designed was to determine the effect of the adaptation of the eyes to various colors, upon the recognition or discrimination of colors.[1]

To illustrate: Suppose it is desired to determine whether green is more easily recognized as green when the eyes have been first stimulated with red, than when they have not been stimulated by any color other than the normal illumination. To answer this question it is first necessary to determine for the normal unadapted eye what percentage of green it is necessary to add to (say) a black in order that a definite greenish hue may be detected in the black. With a series of differential discs such as those described under 2, it is possible to begin with black only and gradually add small increments of green until the observer is definitely able to detect the green component in the black.

The next step is to stimulate the eye by fixating a large sheet of red paper for a definite period and then determine whether the percentage of green which must be added to the black to make it appear greenish is now greater or less than for the normal condition. As will readily be seen this experiment may be modified in many different ways. Industrially,

[1] The apparatus was used for this purpose by Miss Mary Almack, graduate student in psychology. *Jour. of Exp. Psych.*, Vol. I, No. 5, 1916, p. 426.

it may be used to determine the effect of the various types of illumination on the recognition of colors. The apparatus is relatively simple and quickly manipulated so that unpractised observers may be used.

The limen color mixer may be regarded as a combination of four color mixers, any one of which may be shifted to such a position that only a small area of the rotating disc is exposed. The position of the exposed area can be accurately determined by a micrometer screw arrangement; and from these readings the percentages of the color components may be derived. In general the apparatus may be regarded as a device which permits the control of the following conditions:

1. Many different color combinations are promptly available.
2. Only a small area of the color to be judged is exposed.
3. The percentage composition of the exposed color can be accurately determined.
4. By means of differential discs the increments by which a given color or brightness is changed can be made as small as necessary to meet any condition.
5. The length of time that the color is exposed, and the duration of the interval between successive exposures, can be controlled.
6. The exposure shutters move from the center outward when opening, and in the opposite direction when closing, thus eliminating any tendency toward eye movement.

2. Differential Color Discs

The subliminal steps that are necessary for determining color limens or thresholds are secured by superimposing one color upon another in such geometrical proportions that at various distances from the center of the disc, different proportions of the two colors will occur. One of the simplest geometrical shapes that will permit this is illustrated in figure 1. A cardboard disc 10 inches in diameter is the most satisfactory. Larger discs are likely to be torn during rotation and in smaller discs the radii along which the series of combinations is seen, are too short.

Suppose it is desired to pass from black to green by subliminal steps. If a green disc (fig. 1) has pasted on the face of it two circular black discs b, the part marked a will be green, and the part marked b will be black. When this compound or differential disc is then rotated in a color mixer, the resultant colors will vary from black only at the center, to green only at the periphery. Between the center and the

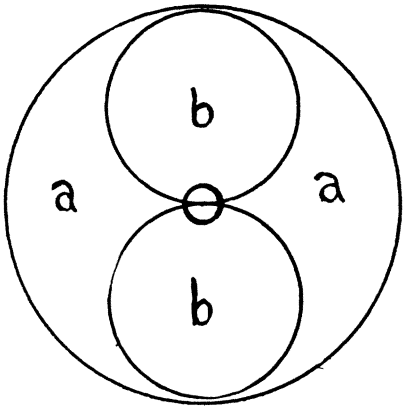

FIG. 1

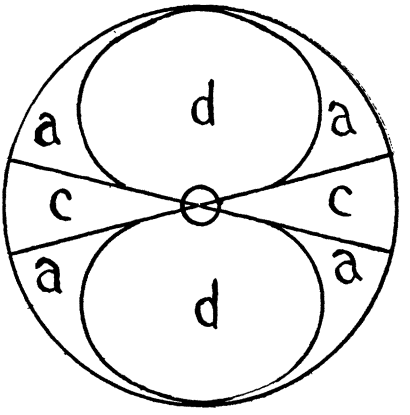

FIG. 2

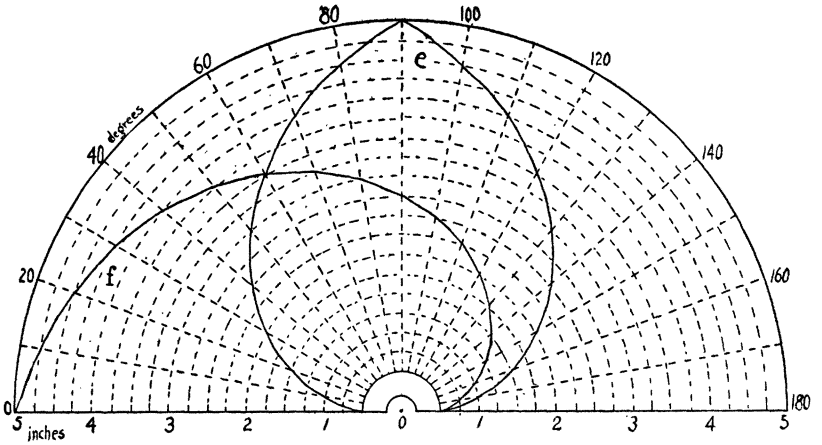

FIG. 3

periphery will be found all possible combinations between black and green. That is, if we consider one of the radii of the disc while it is being rotated, the face of the disc along this radius will not be all of the same color but will be a blended series of blacks and greens beginning with black at the center and becoming more greenish as the periphery is approached, until we have the green of the original color disc.

Referring this combination to the color pyramid we may say that this disc shows all the saturations and brightnesses

of the hue green, between the points black and green on the pyramid. If the circles (b) are a gray of the same brightness as the green, the differential disc will show all the possible saturations of green at the brightness of the original green disc. In this case the series will represent a change in saturation only. By selecting different hues and brightnesses of a and b all the colors between any two points on the pyramid may be shown as a continuous series. By having on hand fifteen or twenty of the various combinations, the demonstration of the color pyramid is much simplified.

Where it is desired to make the steps still more gradual than is indicated in figure 1, a pair of sectors (c) figure 2, of the same color as b may be added. These sectors increase the effect of the b circles by a constant amount, depending on the angular size of the sectors. They may be used also to change the hue of the resultant color. Thus if a is blue, b is red, and c is green, the resultant color on rotation will show combinations of blue, red and green.

In figure 1 the area of the two b circles is equal to the remaining area of the a part of the disc and under these conditions satisfactory series are secured only when the two colors are approximately equal in brightness. Where the differences in brightness between the colors which are to be combined into a continuous series is great, the darker color should cover a larger area than the lighter color. Thus figure 2 represents a combination in which a is light and b dark. Where the difference is very great, as between white and black, it may be necessary to add sectors c of the same color as d. For qualitative work such as class demonstration, b need not be a true circle; but for quantitative work it is simpler, from the geometrical standpoint, to make b true circles, and make whatever changes are necessary by adding the sectors c as was done in the discs shown in the illustrations of the limen color mixer, figures 4 and 5. However, when b is a true circle, the steps from the center outward do not represent equal increments of the color a. The series is geometrical in that the a color is added at first gradually and then more and more rapidly.

To secure equal steps in the addition of the a color with equal steps along the radius, the b color should have the shape of either e or f figure 3. In these shapes equal radial increments are plotted against equal angular increments on polar coördinates. Only one half of the differential disc is shown. The other half is, of course, symmetrical. Where there is difficulty in securing a high speed of rotation it is

best to use the shape e; where the speed is high, the shape f may be used. Both e and f are not, however, to be used on the same disc. If shape f is cut out of colored cardboard or out of another 10 inch disc, it may be used with other circular discs and thus extend its range of usefulness. It is not advisable to try to use shape e independently because it does not fasten so securely as f. These shapes are designed to allow for a thumb nut one inch in diameter. The shapes of e and f are not easily drawn and at best they are only approximations to the true shapes which would be secured if a very large number of points were plotted. Even for quantitative work it was found simpler to use the true a circles of figure 1 and measure the proportions of the a and b colors for any given radius of the disc, with a protractor.

The differential discs described in this section may, of course, be used on any color mixer. They are independent of the limen color mixer.

3. The Limen Color Mixer for Research

When used for research the large sheet iron screen 1 (fig. 4) covers the entire front of the apparatus with the exception of the slot 2 which exposes a shield 4 in which there is a round window 5 that travels from the center to the periphery of whatever disc is in the position 3. The size of window 5 is 5-8 inch in diameter. That is, the only part of the color disc which shows to the observer is the small area which may be seen through the window 5. To illustrate: If a differential disc rotating in position 3, is made up of (a) green and (b) black (fig. 1) the window 5 will expose a small area that will seem to be colored equally all over. If the window is near the center, the color will be less green than when the window is toward the periphery. By means of the screw 6 (fig. 5) the carriage which carries the window 5 and the shutters 19 and 19a, may be shifted anywhere along the radius of the disc, thus securing the various combinations of black and green.

Under ordinary conditions only the disc in the position of the spindle 3 will rotate; any of the other three discs 14, 15, 16, can be shifted quickly to the "running" position by turning the spider 7. By means of this spider the experimenter has four discs or series always available yet not visible to the observer.

The color discs are fastened to the spindles by a thumb nut as in the ordinary color mixers. The position of the window is accurately determined by the screw 6 (fig. 5).

This screw has a pointer on the scale 8 which indicates the number of turns of the screw. At 9 is a circular scale divided into one hundred parts. This is also provided with a pointer. The screw has eight turns per inch and the window 5 is thus moved one eighth of an inch along the radius of the disc for each complete turn of the screw. Since the circular scale 9 is divided into one hundred parts the position of the window may be read to one one-hundreth of an eighth of an inch or .00125 inch (.0318 mm). Assuming that the effective scale is four inches long, this will give a possibility of 3,000 objective steps between the center and the periphery of the disc, each step of which can be secured as often and as accurately as necessary.

This is of course much finer than is necessary for most quantitative work; but in designing the apparatus it was thought best to make the objective steps very small so as to be well within any discriminative limen which would likely be found. Where it is desirable to test the effects of various sources of illumination upon the recognition and discrimination of colors and especially where the changes in the illumination are subliminal, it is necessary to measure small increments in the objective colors very accurately.

The following are some of the research problems for which the apparatus is adapted:

1. Relative influence of hue, brightness and saturation upon each other as determined by discrimination.
2. Effect of various types of illumination (industrial) upon the discrimination or recognition of colors.
3. Effect of selected stimulation (adaptation) upon the discrimination or recognition of colors.
4. Determination of the color composition of after images.
5. Determination of the saturation and brightness limens for color combinations.
6. Effect of the duration of the stimulus and the interval between stimuli upon discrimination and recognition of colors.

4. The Limen Color Mixer for Demonstration

When the color mixer is to be used for demonstrational purposes the screen 1 (fig. 4) and the shield 4 are removed. If it is desired to rotate all four spindles at the same time this is done by passing a round leather belt over the pulleys of all four spindles. This method is used when it is desired to make direct comparisons between different color mixtures, say the different color combinations which will produce gray.

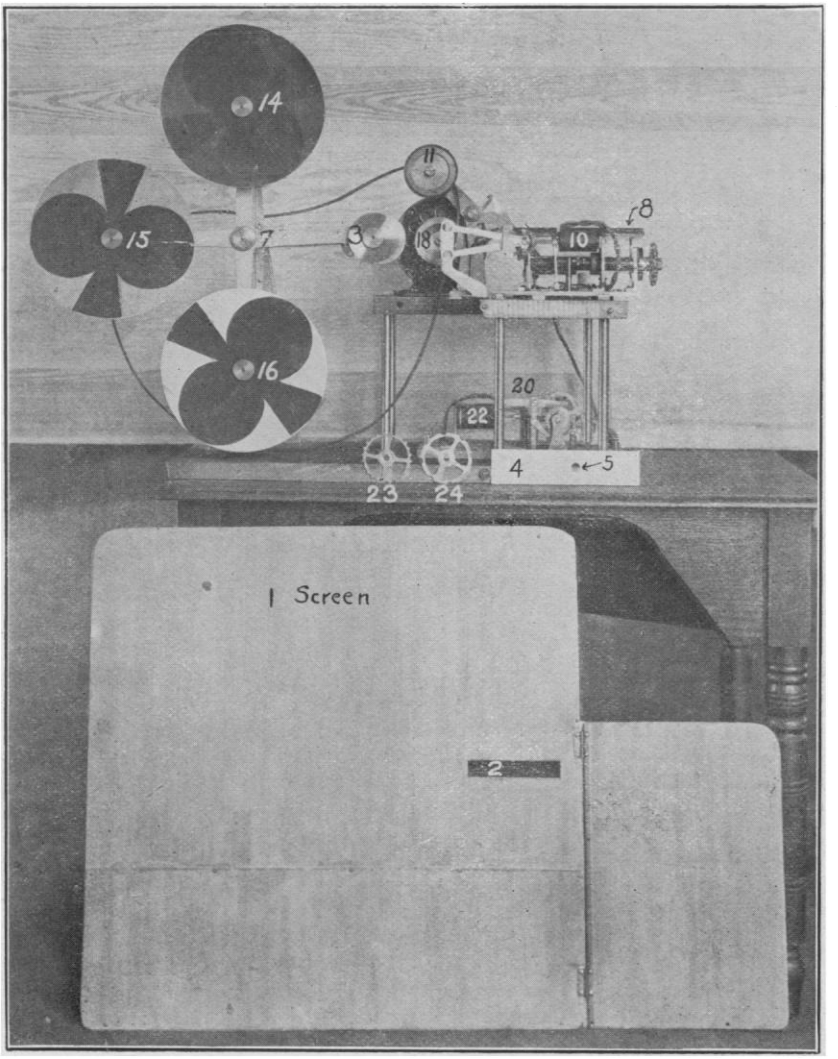

FIG. 4

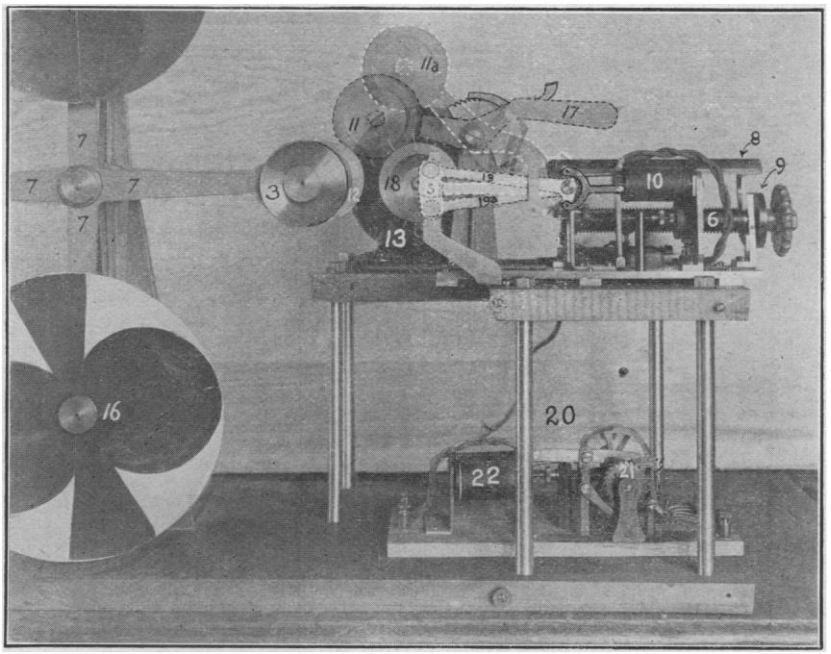

FIG. 5

For class work the limen color mixer lends itself well for the following:

1. Color mixing as it is usually carried out with the ordinary split color discs. Any sized disc up to 10 inches diameter may be used.

2. Continuous series by the aid of the differential discs described in section 2. Where the time is limited about twelve of the differential discs made up of the most important color and brightness combinations are sufficient. For more extensive demonstration, especially where it is desirable to show the manifold interrelations of brightness, saturation and hue combinations, thirty or forty of the differential discs may be profitably used.

3. By using 10 inch discs and having a light gray screen (wall or projection lantern screen) where the class can easily see it, one of the rotating discs may be fixated for a half minute and the after image projected on the screen. Such after images are unusually striking when differential discs are used.

5. Description of Details

The numbers which occur in the following description refer to figures 4 and 5 which are photographic reproductions of the limen color mixer.[2]

Figure 4 shows the apparatus placed on a table with the screen 1 removed and set up against the lower part of the table.

Figure 5 is a reproduction of a phantom photograph of the shutter 19, 19a and idler pulley 11 in both the "on" and "off" positions.

The figures by which the details are numbered refer either to figure 4 or 5.

1. Sheet iron screen, painted neutral gray, which covers the entire apparatus with the exception of window 5.

2. Slot in screen 1 through which window 5 is visible.

4. Tin shield attached to a carriage which is moved back and forth by the screw 6. This shield prevents the observer from seeing the color disc through the slot in screen 1.

5. Window, 5/8 inch diameter through which a cicular area is visible of whatever disc happens to be in the position 3. The distance of this window from the center of the disc is accurately determined by the screw 6. The opening and

[2] The apparatus was constructed by Mr. A. P. Freund, mechanician of the department of physics at the Ohio State University, from sketches furnished by the writer.

closing of this window is brought about by the aluminum shutters 19 and 19a which are operated by the magnet 10 attached to a carriage moved by the screw 6. The shutters open from the center outward and close from the periphery inward.

11. Idler wheel which acts as a friction wheel to turn spindle wheel 12; when in the position 11, the spindle will turn when the motor turns; when in position 11a, it is disengaged and allows the spider 7, which carries the other mixer spindles 14, 15, 16, to be brought into position 3 so that any one of them may be used. The idler 11 is moved by the handle 17 and can be shifted without stopping the motor 13.

13. One-tenth horse-power, alternating current motor, 3,200 revolutions per minute, which drives the color spindles by means of the grooved pulley 18.

20. Timing device modified after Kuhlmann. The ratchet 21 moves one notch whenever the magnet 22 is excited. By a suitable contact device and the proper contact wheels as 23 or 24, the window 5 can be kept open or closed for any period of time. To illustrate: Time wheel 23 has its contact teeth arranged in such a way that when the timer 20 is tripping once per second, the window 5 will give one instantaneous exposure per second. With wheel 24 the window will stay open two seconds and close one second (or the reverse). By selecting the proper wheels any relation of interval and exposure may be secured. The timer 20 is controlled by a pendulum or metronome which makes and breaks the electric current that excites the magnet 22. This pendulum is not shown because it is not an essential part of the apparatus. The pendulum which is used with the apparatus at Ohio State University is a duplex, self-acting electric pendulum designed by the writer. It has been used in many other experiments and has proved so reliable and satisfactory that its construction and method of operation will be the subject of a separate article.